

Spectrum management and rebanding

Quantifying channel capacity ensures comparable facilities and interference mitigation

The first wave of 800 MHz rebanding is scheduled to begin later this month, and spectrum management is a key factor in ensuring the efficient use of a very precious resource. As we have already seen, poor management leads to conflicts and poses serious consequences for public safety and homeland security.

Identifying and measuring interference once was a difficult and costly procedure, as the methodologies had been constrained by a lack of affordable and reliable high-performance tools to deal with a complex problem. But now the bottleneck preventing the accurate identification of external interference has been eliminated, resulting in capabilities that were not available when the FCC's order was written.

This article will describe how to manage spectrum to maximize its potential and how to mitigate interference during and after rebanding. With cost-effective ways to identify and measure interference, rebanding activities can occur in a fiscally responsible manner.

The main impetus for the 800 MHz proceeding is to provide a better spectral environment for public safety and critical infrastructure industries. The order addresses this in three steps:

- It establishes standards for harmful interference now and in the future, and establishes the procedure to report interference, identify who is causing it and who should resolve it.

- It eliminates a major cause of interference by rebanding and provides

ent as possible to the end user. Specifically, (1) equivalent channel capacity, (2) equivalent signaling capability, baud rate and access time, (3) coextensive geographic coverage and (4) operating cost."

Ensuring that comparable facilities

Equation 1

$$\text{CHANNEL CAPACITY} = \text{BW} \times \text{LOG}_2 \left[1 + \frac{C}{I} \right]$$

Source: AIM Wireless

"comparable facilities" to those that must change frequencies.

- It resolves any remaining problems through interference mitigation.

According to the FCC's definition, comparable facilities "will provide the same level of service as the incumbent's existing facilities, with the transition to the new facilities as transpar-

are provided is an enormous engineering challenge. One must consider the hardware configuration, the RF domain and interference. The hardware configuration directly addresses receiver sensitivity, noise figure, thermal noise and the modulation scheme. Various vendors and their mobile radio dealers will perform hardware config-

Continued on page 40

Table 1

GPS TIME	LATITUDE	LONGITUDE	FREQUENCY	RSSI
0:12:34	41.876217	-87.63465	870.42	-60
0:12:34	41.876217	-87.63465	870.45	-43
0:12:34	41.876217	-87.63465	870.48	-90
0:12:34	41.876217	-87.63465	870.51	-95

Source: AIM Wireless

Channel capacity is the single most important element of defining comparable facilities, and interference is the sole variable that determines whether channel capacity is adequate after rebanding.

uration and handset tuning. It will not be difficult to deliver the required signal strength, baud rate, access time and proper coverage.

Similarly, radio frequency (RF) network engineers can manage RF configuration factors such as effective radiated power and fading (fast fading or long fading) at a reasonable cost.

Delivering a sufficient level of RSSI (received signal strength) is a part of the network implementation. Both hardware configuration and RF configuration are controllable factors internal to a network and are not changed in the rebanding process; essentially, they are constants when looking at comparable facilities.

Interference is a more complex issue. There are two types of interference, internal and external. Internal interference consists of co-channel and adjacent-channel interference. These are the easiest to identify and correct. They will surface in the post-rebanding environment only if they existed in the pre-rebanding environment. They can be avoided through proper network design.

External interference includes intermodulation, wideband noise (out-of-band emission) and receiver-spurious interference. External interference occurs whenever the right combinations of frequencies occur under the right conditions in the environment. These are signals that come from some other network.

It is the external interference prob-

Need remotes? Call Us



CPI manufactures a broad line of DC, Tone, Local Extension, Multi-Channel, and Multi-Line remotes and termination panels for most radio systems.

The CPI line of Multi-Channel remotes include systems for the Kenwood -80 (TSR412/TSP402) and -90 (MCP411/MCP401) series and many Motorola models including the CDM1550(LS), (MCR211A/MCP200C) and the M1225 Series. For additional information on the complete CPI line of products please call us or visit our website.



941 Hensley Lane • Wylie, TX 75098
Phone: (800) 869-9128 (972) 429-7160
Fax: (972) 429-7165
www.cpicomm.com

Interoperability & Radio over IP Solutions, Without the Red Tape



With budgets disappearing, deadlines fast approaching and liabilities looming, let **Catalyst Communications Technologies** be your **Number One Source** for radio interoperability without the hassles of red tape and costly overhead.

Catalyst is redefining the perception that safety is not affordable, dependable and flexible -- call us today!


catalyst
communications technologies

contact us at: 434.582.6146
www.catcomtec.com

lem that the FCC's 800 MHz order addresses. External interference is a complex issue, and it will not go away simply by rebanding. External interference cannot be predicted, nor can it be accounted for in the process of rebanding, without proper analysis. Most important, external interference directly impacts channel capacity, access time, throughput and operating cost.

Channel capacity is the single most important element of defining comparable facilities, and interference is the sole variable that determines whether channel capacity is adequate after rebanding.

By measuring the levels of signal strength and interference, you can quantify channel capacity. Without measuring the level of external interference, you cannot determine what impact it has on comparable facilities. This

must be done before and after rebanding, according to standard engineering methodology and best practices.

What is channel capacity? More than 50 years ago, the Bell System Technical Journal published Claude Shannon's article, "A Mathematical Theory of Communications," that provides a mathematical framework for communications engineering and contained the Shannon Theorem (see Equation 1 on page 36).

Channel capacity is a function of three elements: channel bandwidth (BW), carrier power (C) and cumulative noise, i.e., interference (I). Channel capacity increases when interference is decreased. Bandwidth and the signal strength variables are internally controllable elements. External interference, as discussed earlier, is an environment-dependent variable.

To objectively determine that com-

parable facilities have been provided, we need to execute three conceptually simple steps:

■ Measure the channel capacity for each channel before rebanding occurs.

■ Measure the channel capacity for the new replacement channel.

■ Compare the two values, and it will be obvious whether you received equivalent channel capacity.

Because rebanding will create changes, many new factors will be introduced that may cause external interference. Even channels that are not being rebanded and were operating normally may be affected. The process that follows can provide essential information about interference.

By measuring channel-capacity components before and after rebanding, all possible errors

BMS Series Battery Management Systems

NEW

CAGE CODE:
32AR9



Usable with any
existing power supply!

- Only 1 rack unit high; 1 3/4" X 19" (W) X 10 1/4" (D)
- 12 volt units handle up to 75 AMPS
- 24 and 48 volt units handle up to 50 AMPS
- Smart Charger, LVD and Diode Isolation System.
- Smart charging for optimal charging. Highly recommended for deep cycle or gel cell batteries. Front panel indicator for battery status. Battery polarity protection.
- Low voltage disconnect. Stops battery damage due to overdischarge. Auto reconnect when power is restored. Disconnects battery at an adjustable voltage.
- Diode isolation system provides isolation and seamless transfer to battery when power goes down. No relays to fail. No "glitches" to confuse processors and controllers.

Call or Fax Us Toll Free

Phone 1-800-467-6741 Fax 1-800-825-1403

DuraComm
CORPORATION

203 W. 23rd Ave.
North Kansas City, MO. 64116

On the Web at www.duracomm.com
Email: duracomm@duracomm.com

YOU Told Us What You Wanted



COM3010 Communications Service Monitor

- ✓ 100kHz - 1.0GHz, Full Duplex!
- ✓ ± 0.1 ppm Frequency Accuracy!
- ✓ Built-in Power Meter & Load!
- ✓ Built-In Frequency Counter!
- ✓ Built-In Sweep Generator!
- ✓ Built-In SINAD Meter!
- ✓ Built-In Calibrated RSSI Meter!
- ✓ Built-In RS232 Control
- ✓ Built-In Li-Ion Battery Pack

As Low As
\$3995!

STE Series RF Shielded Test Enclosures

- ✓ Wireless Device Testing
- ✓ Cellular, PCS, GSM Testing
- ✓ Bluetooth, RFID, 3G Testing
- ✓ 802.11a, b, g Testing
- ✓ RF Radiation Test Fixture Models
- ✓ Super Isolation Up To 18 GHz!
- ✓ Stock Models To Fit Your Custom Applications!
- ✓ Variety of I/O Options

As Low As
\$439!

We Listened...Consider It Done!

ramsey
electronics inc.

RAMSEY ELECTRONICS, INC.
590 Fishers Station Drive
Victor, NY 14564
(585) 924-4560
www.ramseytest.com

For decades, your
leader in cost
effective, high
performance RF
Test Equipment!

Specifications, prices, and lease terms subject to change. Contact Ramsey for additional information.

Table 2**Before rebanding**

1	Frequency (MHz)	866.225	
2	Length of route (miles)	1000	
3	Number of segments (300 ft. segments)	17600	
4	Number of segments that do not have signal adequacy	35	
5	Signal adequacy	0.19	%
6	Average signal strength (dBm)	-75	
7	Number of intermodulation interference locations	655	
8	Intermodulation Interference	3.72	%
9	Number of wideband interference locations	755	
10	Wideband interference	4.29	%
11	Number of receiver spurious interference locations	325	
12	Receiver spurious locations	1.85	%
13	Total number of interference locations (deadspots)	1735	
14	% of total interference locations (deadspots)	9.85	%

After rebanding

1	Frequency (MHz)	851.225	
2	Length of route (miles)	1000	
3	Number of segments (300 ft. segments)	17600	
4	Number of segments that do not have signal adequacy	20	
5	Signal adequacy	0.11	%
6	Average signal strength (dBm)	-75	
7	Number of intermodulation interference locations	320	
8	Intermodulation Interference	1.8	%
9	Number of wideband interference locations	410	
10	Wideband interference	2.3	%
11	Number of receiver spurious interference locations	50	
12	Receiver spurious locations	0.28	%
13	Total number of interference locations (deadspots)	780	
14	% of total interference locations (deadspots)	4.43	%

Source: AT&T Wireless

(human or otherwise) that may result from the rebanding process can be captured and identified. To measure this, create a baseline of your coverage area.

A baseline plan should include a map that denotes the exact routes to be driven. Collect a continuous wave (CW) for the received signal strength indicator (RSSI) for the entire band, from 851 MHz to 895 MHz. This band includes public safety, Nextel, SMR op-

erators, Cellular-A and Cellular-B. Data should include location and the timestamp information. This collection process provides field data with RSSI levels for each frequency, at a specific location identified by latitude and longitude, at a specific time of day (see Table 1 on page 36).

Collect information about the channels to be rebanded, including receiver characteristics (receiver sensitivity, in-

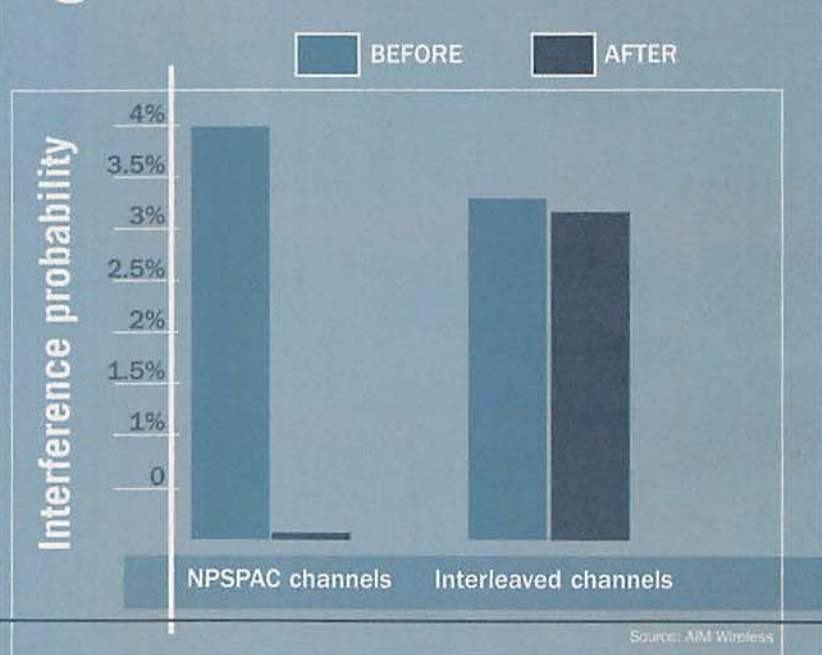
termodulation rejection and adjacent band rejection) and the exact frequencies being rebanded. Process the scanned data against the rebanded channels and run an interference analysis for intermodulation interference, wideband noise and receiver-spurious noise.

Once this information is processed, produce a comprehensive report for each channel to include RSSI, inter-

modulation noise, wideband noise, receiver-spurious noise and signal adequacy. Plot the pertinent information on maps of your coverage area. This information constitutes a baseline for comparison after rebanding. The analysis of the data includes the locations and number of dead spots for each channel.

After the actual frequency changes are made to the base station or transmitter, a second drive test should be conducted along the same routes covered in the baseline. The process is repeated, and the results of the second test are compared to the results of the first test (see Table 2 on page 42). The difference in these values will provide a clear picture of the before and after in the environment. These same values should be examined to determine whether comparable facilities have been provided.

Fig. 1



Mobile Command **Dispatch Operations** **First Responders**

Radio Control Console

with Cross-Banding!

The NCS-C250 Mobile Multi-Switcher is a much needed interoperability solution for Public Safety professionals. The unit connects four radios to one microphone and two speakers and includes cross-band repeating and selected & unselected audio control. Options include COR, Hook-Switch and Multi-Cast. Multiple units in series control eight or more radios. Radio interconnect cabling is also available.



Dimensions
1.8" H x 6.4" W x 7.1" D

NCS-C250 Mobile Multi-Switcher



TRANSMITTER LOCATION

New fixed site direction finders provide 2 degree accuracy, and include software for triangulation from a central control site. Mobile versions also available covering 50MHz to 1 GHz

Doppler Systems Inc.

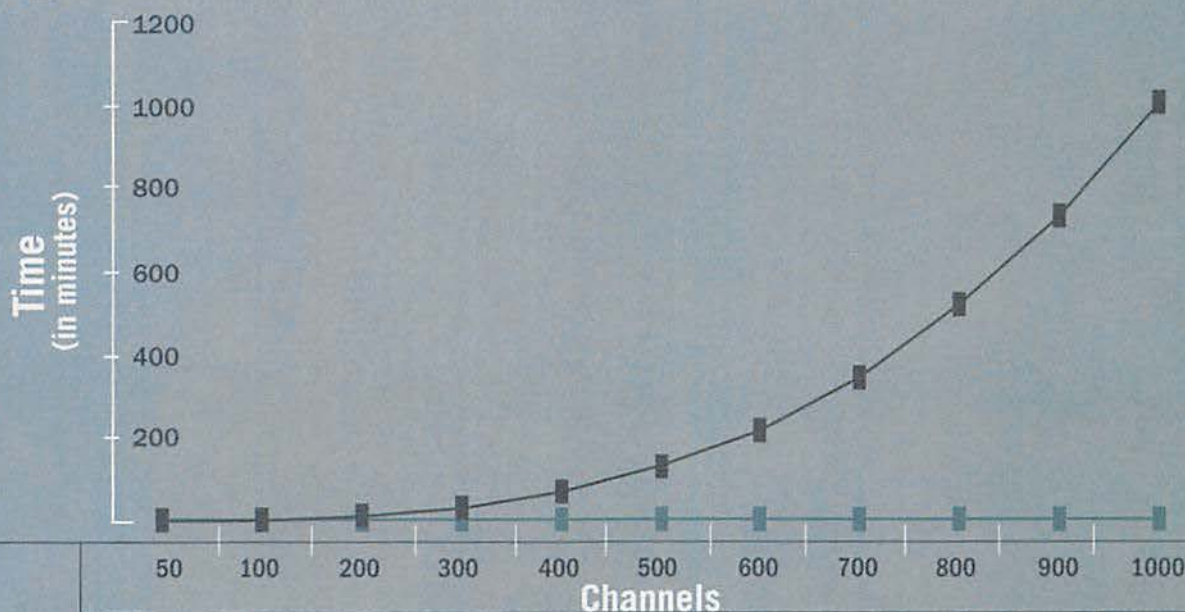
PO Box 2780 Carefree, AZ 85377
Tel: (480) 488-9755 Fax: (480) 488-1295
www.dopsys.com

European Marketing Director Denis Egan
PO Box 2, Seaton, Devon EX12 2YS England
Tel & Fax: 44 1297 62 56 90



888.883.5788
mfr@ncsradio.com
www.ncslc.net

Fig. 2



Source: AM Wireless

Though the rebanding process provides significant improvement to some parts of the spectrum, such as the NPSPAC channels, many public-safety and critical infrastructure industry (CII) channels will not improve (see Figure 1 on page 44). The fact that some of the public safety and CII channels will still suffer interference is no surprise.

The FCC's 800 MHz order recognizes this: "Based on the extensive and comprehensive record of the proceeding, we are convinced that neither band reconfiguration alone, nor application of 'technical fixes' on a case-by-case basis, would

adequately address the interference to 800 MHz public-safety communications systems."

Interference mitigation is achieved by the use of post-processing tools and software. These tools must have the capability of importing and analyzing field data so that the source of the problem can be identified and resolved. The mitigation process can be summarized as follows:

- Collect data.
- Identify the problematic area.
- Import data into a simulation tool.
- Process the data.
- Perform what-if scenarios to identify the problem and find a solution.

Mitigation can be a daunting task, particularly if the number of channels analyzed exceeds 500 channels—a common scenario in an urban environment. Existing tools process an interference study by comparing each channel sequentially (Figure 2). This leads to billions of calculations that must be processed, a process that can use all of a PC's memory and crash the system before completing the task. The simulation tools must have fast processing capabilities to provide timely results. When processing grows from hours into days, it will be impossible to meet the mitigation deadlines imposed in the 800 MHz order. Reducing the amount of data processed by arbitrarily deciding what not to

dbSpectra Homeland Security Solutions

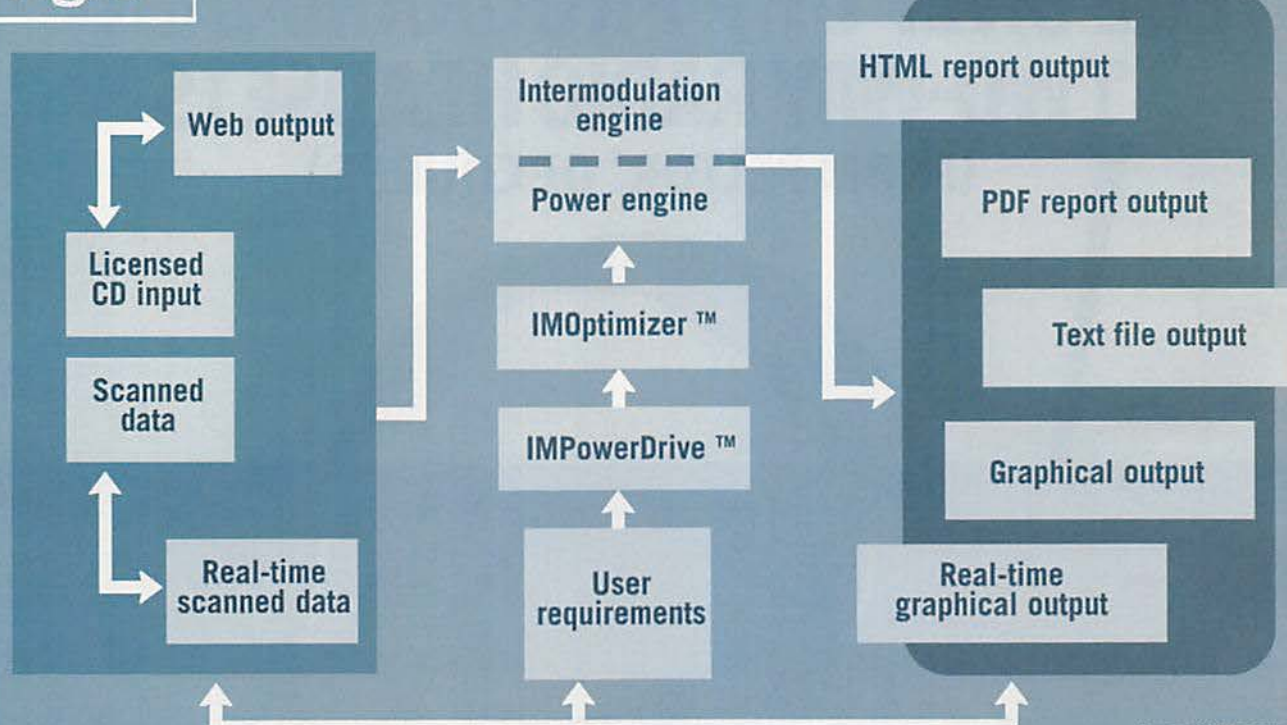
30-960 MHz
Cavity Filters
Duplexers
Transmit Combiners
Tower Top Amplifiers
Receiver Multicouplers
Control Station Combiners
Systems Integration



Phone: 972.389.0595
Email: sales@dbSpectra.com

www.dbSpectra.com

Fig. 3



Source: AIM Wireless

MDC-1200® | GE-STAR® | FleetSync™ | DTMF Multi-Format ANI Decoders



Having Compatibility Issues?

Always Know Who You're Talking To

- Supports MDC-1200, GE-STAR, FleetSync and DTMF all in one unit
- User configurable serial output port for most major console manufacturers
- 36-character alpha numeric display
- Encoding and multi-channel options available
- Flash upgradeable

Call or visit the web site for complete info and pricing.

800-487-7184
www.cimtechcorp.com



CIMARRON
TECHNOLOGIES

process reduces an interference study to guesswork.

The bottleneck in speed is eliminated by a significant advance in how an intermodulation study is processed with AIM Wireless's InterMod60 (Figure 3). Because IMOptimizer and IM PowerDrive are built on the InterMod60 engine, speed is not an issue. The mitigation process can be executed effortlessly, and proven engineering methodologies can be applied.

Input is the fuel to process information—the raw data collected in the field. Data collection is not difficult, but defining the type of data and the collection process is critical to getting the right information. To illustrate this, we will start with the essential data that is needed to run an interference analysis—power and frequency.

By using this methodology, interference can be mitigated before and after rebanding. The same procedures used to create a baseline can then be repeated to objectively determine whether comparable facilities have been delivered to the licensee. The bottlenecks indeed have been eliminated. ■

Ahmad Malkawi and Mohammed Malkawi have spent their careers in RF engineering and high-speed software architecture. They can be reached by e-mail at amalkawi1@aimws.com and mmalkawi@aimws.com or through the AIM Wireless Solutions Web site www.aimws.com.

The finer points of rebanding

Follow these tips to eliminate receiver intermodulation and out-of-band emissions

Last month's Tech Speak focused on techniques for measuring interference in the 800 MHz band, both during and after the rebanding process, and touched upon strategies to mitigate that interference. This month, we examine mitigation techniques in greater detail.

Before the FCC last summer ordered Nextel Communications to reband the airwaves over the next three years, many licensees questioned whether rebanding by itself actually would eliminate interference. These skeptics were correct as rebanding by itself does not eliminate interference. Instead, it creates necessary conditions so that two important mitigation techniques become effective. This article describes how Nextel can put these mitigation techniques to use after rebanding.

Let's begin with a refresher on the types of interference created by Nextel and the A-Band cellular carrier. This interference affects the portable radio receiver (not the repeater receiver) and falls into two categories:

- Receiver intermodulation is a non-linear combination of two or more interfering signals inside the receiver front-end (low-noise amplifier and/or mixer).

- Out-of-band emissions (OOBE) comprise radio frequency energy that falls outside the assigned channel

for the transmitter. OOBE includes radio carrier harmonics, transmitter intermodulation products, and broadband transmitter noise typical of digital radio transmitters.

A block diagram for a typical public-safety radio receiver is shown in Figure 1. Public-safety receivers are vulnerable to receiver intermodulation because the front-end bandpass filter must pass all frequencies from 851 MHz to 869 MHz. Nextel frequencies fall within this same band, so the low-noise amplifier that follows the bandpass filter is exposed to strong interfering signals that mix within the amplifier.

An intermodulation, or IM, product between two interferers with frequencies f_1 [lower

frequency] and f_2 [higher frequency] can be represented mathematically, as depicted in Equation 1. Using this formula, two interferers operating at 861.4875 MHz and 862.4875 MHz will create the third-order IM products inside the 800 MHz band depicted in Equation 2.

An important rule-of-thumb for two-transmitter, third-order products is that the products will fall exactly $\Delta = f_1 - f_2$ below the lower frequency and above the higher frequency. It also should be noted that three interferers also can create third-order products, which take the form $A+B-C$ rather than $2A-B$, and that three-carrier products are more numerous than two-carrier products, as shown in Equation 3.

Generally—given a set of poten-

Equation 1

$$f_{im} = nf_1 + mf_2$$

Where n and m are non-zero integers. The order of the product is simply the sum of the absolute values of the coefficients, $|n| + |m|$.

Equation 2

$$2(861.4875 \text{ MHz}) - 862.4875 \text{ MHz} \\ = 860.4875 \text{ MHz}$$

$$2(862.4875 \text{ MHz}) - 861.4875 \text{ MHz} \\ = 863.4875 \text{ MHz}$$

Figure 1

Typical public-safety receiver front end

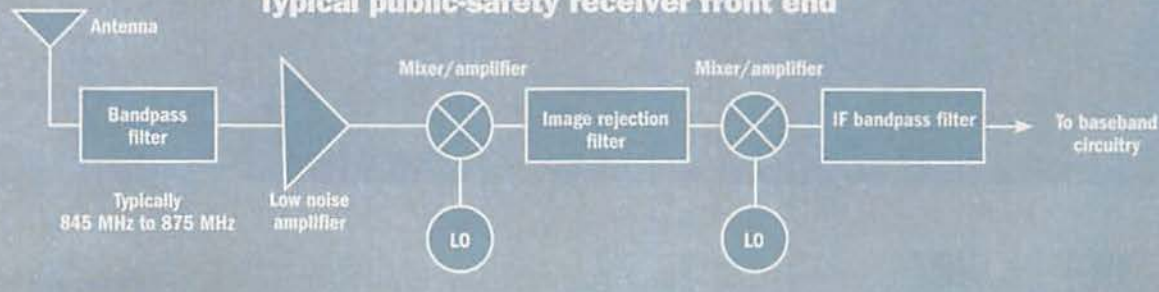
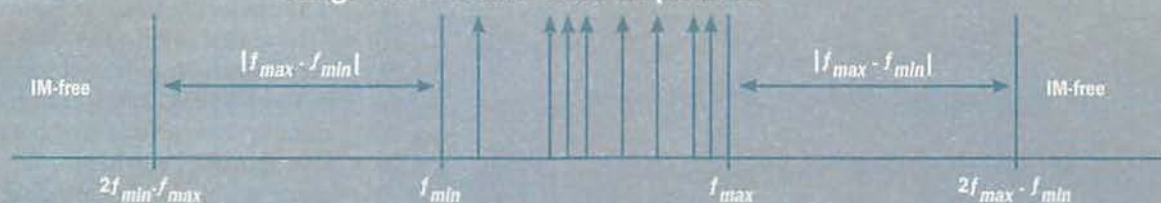


Figure 2**Range limits of third-order IM products**

tial interfering frequencies that fall within the range $[f_{min}, f_{max}]$ —no third-order product can fall farther than $\Delta = f_{max} - f_{min}$ below f_{min} or above f_{max} . A sufficient condition to preclude third-order IM products is stated mathematically in Equation 4 on page 22, while this principle is shown graphically in Figure 2. Note that this article is focusing on third-order products exclusively. While fifth-order products do occur, they usually are weak enough in a Class A receiver that they can be ignored.

Given Figure 2, a simple way to eliminate receiver intermodulation is to first create a guard band between dissimilar services and then

Equation 3

Three-carrier products

$$= N(N-1)(N-2)/2$$

Two-carrier products

$$= N(N-1)$$

Where N is the number of transmit frequencies.

ensure frequency sets for the interfering service (e.g., Nextel) have a span no greater than the span of the guard band. Because guard bands waste spectrum, it is important to limit the number of band edges between the two dissimilar services so only one guard band is required. This is precisely what the FCC has done with its rebanding plan.

The 851 MHz to 869 MHz band now

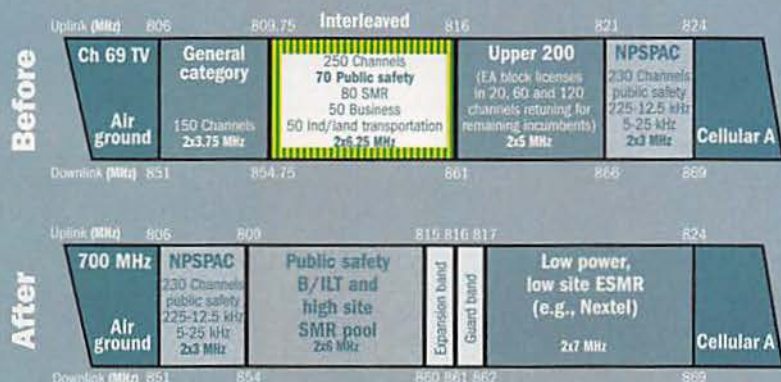
**JUST ONE MORE WAY WE'RE PROVING TO BE
THE MOST FLEXIBLE COMPANY TO WORK WITH.**

You asked for an antenna that would eliminate replacement costs and reduce down time. We've responded with the Flexi-Whip Antenna. It includes a mast that bends, but easily returns to its original shape. Plus, the Flexi-Whip is just one of the antennas we've designed specifically for the Public Safety sector — with the same high quality and craftsmanship you've come to expect from us. To learn more, call 866.307.8426 or visit sti-co.com.

STICO
coming through.

Figure 3

FCC spectrum allocation



consists of four sub-bands as shown in the before segment of Figure 3.

Note that public-safety channels occur in the interleaved band and in the NPSPAC band. Interleaving alone creates insurmountable problems, but the four band edges also create problems. The proposed rebanding in the after segment of Figure 3 reduces the band edges from four to one and effectively creates a 2 MHz guard band where Nextel has agreed to certain significant service restrictions.

The 2 MHz between 860 MHz and 862 MHz is subdivided into an expansion band (860 MHz to 861 MHz) and a guard band (861 MHz to 862 MHz). No public-safety system is required to remain in or relocate to the expansion band, although they may do so voluntarily. The level of protection afforded in the expansion band creates the effect of a pseudo-guard band, which has a twofold purpose: It allows bandpass filters at the cell site to roll off, and it enables Nextel to create channel plans with intermodulation products that fall in the guard band, but not on public-safety channels.

After rebanding, the solution to OOB is straightforward. Each of Nextel's transmit antenna sectors in potential problem areas should have a cavity bandpass filter designed to pass 862 MHz to 869 MHz and reject

Equation 4

$$f_r < 2f_{min} - f_{max} \text{ or } f_r > 2f_{max} - f_{min}$$

Where f_r is the nearest receive frequency requiring interference protection.

Equation 5

$$2f_{min} - f_{max} > 860 \text{ MHz}$$

Set	Span	Channels	f_{min} (MHz)	f_{max} (MHz)	Lowest IM sector (MHz)	Lowest IM cell (MHz)
A1	675 kHz	27	862.0125	862.6625	861.3625	
A2	675 kHz	27	862.6875	863.3375	862.0375	860.0125
A3	675 kHz	27	863.3625	864.0125	862.7125	
B1	825 kHz	33	864.0375	864.8375	863.2375	
B2	825 kHz	33	864.8625	865.6625	864.0625	861.5875
B3	825 kHz	33	865.6875	866.4875	864.8875	
C1	825 kHz	33	866.5125	867.3125	865.7125	
C2	825 kHz	33	867.3375	868.1375	866.5375	864.0375
C3	850 kHz	34	868.1625	868.9875	867.3375	

Potential frequency sets (compatible with N=3 re-use) (A, B, C=cell; 1, 2, 3=sector)

all frequencies below 860 MHz by at least 45 dB.

The solution to receiver IM also is straightforward. The objective is to create channel sets using all of Nextel's rebanded channels (280 total) without creating any third-order IM products on or adjacent to a public-safety channel. For each Nextel channel set with a minimum frequency [f_{min}] the maximum frequency [f_{max}] must obey the rule depicted in Equation 5.

There are many feasible solutions to this problem. Using a seven-cell, sectored re-use pattern with 280 total channels, Nextel only requires 13 channels per sector [280/7/3]. A three-cell reuse pattern requires 31 channels per sector. For an iDEN system, three-cell re-use is likely to be a worst-case scenario.

We know that Nextel can combine adjacent channels on the same sector antenna using hybrid combiners. Thus, 13 channels require only 325 kHz and thirty-one channels require 775 kHz. But the proposed effective guard band is 2 MHz, so feasible solutions exist. A potential frequency set is listed in Table 1 on page 23.

Note from Table 1 that we have limited the range of frequencies in each cell site (three sectors total) so IM products that would occur between sectors still fall above 860 MHz. Thus, a public-safety receiver operating in the overlap region between sectors is still protected.

Channel sets A1, A2 and A3 have less than 31 channels, but these sets can be assigned to relatively low-capacity sites.

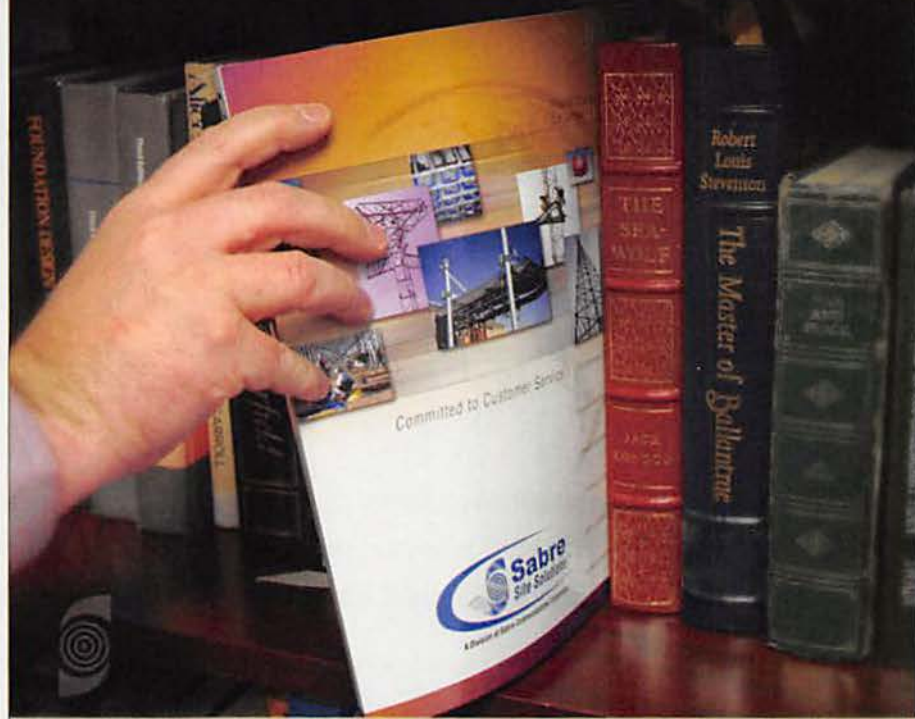
Table 1 is only one feasible solution. There are literally hundreds of practical solutions that meet Nextel's capacity needs while fully protecting public safety from all third-order IM products. Any channel set that obeys Equation 5 within a sector and between adjacent sectors is a feasible solution. Of course, Nextel does not consult the author when preparing its

frequency plan, so the company might take a different approach.

So, is interference eliminated entirely? No. There are still isolated opportunities for interference to occur, especially at Nextel/A-Band co-location sites. These require special attention and exist to keep the consulting engineer gainfully employed. ■

Jay Jacobsmeier is president of Pericle Communications Co., a consulting engineering firm located in Colorado Springs, Colo. He holds bachelor's and master's degrees in Electrical Engineering from Virginia Tech and Cornell University, respectively, and has more than 20 years experience as a radio frequency engineer.

A New Great Classic



EVERY SO OFTEN A BOOK COMES ALONG that is better than all the rest. One that stands out among the crowd, and is used over and over again. Sabre Site Solutions' new Product Catalog is a classic components catalog. The most comprehensive catalog in the tower industry, it offers everything from pre-engineered structures to tower components and accessories. With kitted product offerings, an expanded antenna mounting section and product information to make your purchasing decision easier, Sabre Site Solutions' catalog is a masterpiece among component catalogs.

Request your copy of this great classic today.



A Division of Sabre Communications Corporation

Call toll free **1-866-4-A-TOWER** (866-428-6937)